*SAE TECHNICAL
PAPER SERIES*

950762

Intelligent Braking for Current and Future Vehicles

Donald E. Schenk, Richard L. Wells, and Jon E. Miller
Delco Chassis

Reprinted from: Advancements in ABS/TCS and Brake Technology
(SP-1075)

*The Engineering Society
For Advancing Mobility
Land Sea Air and Space®
INTERNATIONAL®*

International Congress and Exposition
Detroit, Michigan
February 27 - March 2, 1995

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (412)776-4841 Fax:(412)776-5760

950762

Intelligent Braking for Current and Future Vehicles

Donald E. Schenk, Richard L. Wells, and Jon E. Miller
Delco Chassis

INTRODUCTION

The automotive and light truck market is continuing to sharpen its focus on fuel efficiency and safety. Vehicle brake system design is evolving to meet these needs but the demand continues for enhanced level of performance and value. The challenge facing the brake system designer is to engineer systems that appropriately address these needs, plus more.

Future vehicle brake technology must comprehend the increasing requirements for (1) closed loop control of the normal braking event to minimize variability and provide active control of front-to-rear and side-to-side brake balance; (2) active proportional, independent wheel brake control to produce ABS and traction control, handling management, and interface with collision avoidance systems; (3) controllable input ergonomics to provide optimum driver control and comfort and; (4) appropriate interfaces with other vehicle operating systems including powertrain and, in some cases, energy recovery systems., In short, the future demands intelligent brake control.

A number of brake systems have been developed at Delco Chassis to address these needs for current and future vehicles. These systems utilize the proven technology of ABS VI, including truly proportional actuators controlled by sophisticated algorithms. These technologies extend driver performance during normal operating conditions, and optimize vehicle performance when extreme situations occur.

This paper reviews two variants of intelligent brake control. The first consists of a four-wheel electro-hydraulic apply brake system. The second utilizes a front electro-hydraulic apply system with rear electro-mechanical wheel brakes (known as rear electric brakes). Examples will show how the systems fulfill the previously mentioned evolving requirements for brakes.

ELECTRO-HYDRAULIC APPLY

The basic electro-hydraulic brake apply system is an application of full electronic brake control based upon motor/piston technology with hydraulic "push through" for "no power" redundancy. It offers full four-wheel control with features that enhance and augment a vehicle's braking capabilities. Since most vehicles require augmentation to the modulator to provide ABS and traction control function, it was only logical that other brake system functions be combined for mass, cost, performance and packaging advantages. Power assist and traction assist are two examples. The implementation of micro-processor managed electronic modulation of brake pressure also facilitates communication with other vehicle systems including the propulsion system for regeneration and adaptive cruise.

The electro-hydraulic apply system shown in Figure 1 operates in the following manner:

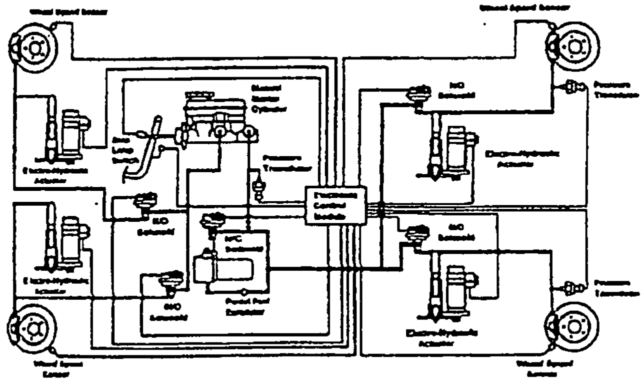


Figure 1 - Four Wheel Electro-Hydraulic Apply

When the brake pedal is depressed, the stop lamp switch closes and a signal is sent to the electronic control module (brake controller) to close the normally-open solenoids. The hydraulic fluid pressure resulting from the brake pedal force is measured by pressure transducers located upstream from the solenoids. The electrical signal from the transducers, proportional to the pedal force, is read by the brake controller and the piston displacement/motors are actuated to produce proportional downstream pressure to the front friction brakes. Pressure is modulated by the signal from the pressure transducers. The rear friction brakes are applied proportionately to give ideal braking balance based on a complex slip control algorithm. An example of brake proportioning with dynamic control is shown in Figure 2.

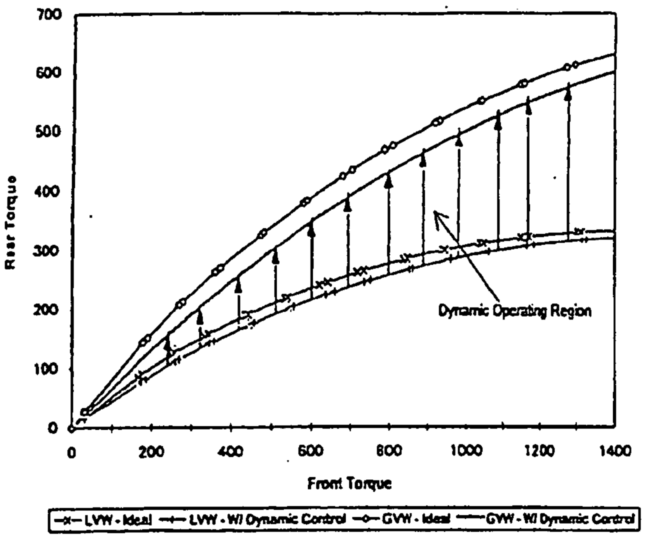


Figure 2 - Brake,System Dynamic Proportioning

Pedal feel during normal braking is achieved by displacing the fluid from the master cylinder during a brake application into a pedal feel emulator device. The closed solenoids in the system prevent master cylinder fluid from being displaced to the wheel brakes during normal system operation. The pedal feel emulator provides a predefined force/displacement relationship which gives the driver the feel of a conventional brake system. In addition, the pedal force/deceleration relationship is tunable by the brake algorithm. Thus pedal ergonomics can be tuned for virtually any desired feel.

During normal power brake operation, hydraulic fluid is displaced to the wheel brakes only by the modulator actuation (motor/piston) as commanded by the controller based on driver input. If a fault is detected within the brake system that merits its being shut down, the normally-open solenoids return to the open position. This then allows brake fluid to be displaced directly from the master cylinder to the wheel brakes (no power manual brakes). The total system is designed to meet all "no power" stopping requirements.

The twin downstream pressure transducers read actual wheel brake pressure and feed that information back to the brake controller to ensure that actual pressure is equal to command pressure. Thus the system assures braking stability and balance.

While the brakes are actuated for an extended period of time and the vehicle is stationary, the electric motors are shut off and locked from back-driving by deactivating an electro-mechanical friction device. Thus, generated wheel brake pressure remains constant. This conserves energy while maintaining braking at the wheels. Any change in driver input causes the system to revert to the normal braking mode.

Normal ABS and traction control functions are achieved by overriding the driver input with an appropriate brake control command, based upon wheel speed. These functions and corresponding algorithms are similar to current production ABS/TCS systems.

A second mechanization is the application of the rear electric brake.

REAR ELECTRIC BRAKE

The rear electric brake system option is particularly well suited for those vehicles which focus on low mass and high fuel economy. Typical mass savings range from 3 to 6 kg. by eliminating the park brake cable mechanism. The rear electric brake system can be used in conjunction with a front electro-hydraulic system, or with conventional front hydraulic brake systems. A sample system schematic showing front electro-hydraulic apply and rear electric brakes is shown in Figure 3.

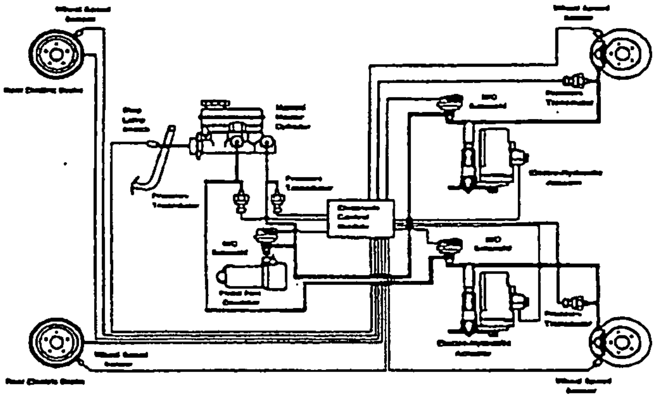


Figure 3 - Electro-Hydraulic with Rear Electric Brake

The rear electric brake is a high gain electro-mechanically actuated design. A high gain wheel brake maximizes the torque capability and minimizes electrical energy requirements. Dynamic stability of the gain is achieved via closed loop control technology. For example, at an operating torque of 400 NM each wheel brake can respond in closed loop control mode at rates up to 4000 NM/second to continuously (>10 ms loop time) adjust dynamic brake output.

Integral to the wheel brake is a permanent magnet DC motor, gear train, and ball screw/nut mechanism. The ball screw converts rotational motion/torque to linear motion/force. This, in turn, actuates a conventional friction surface brake mechanism through a system of levers. A diagram of the wheel brake is in Figure 4.

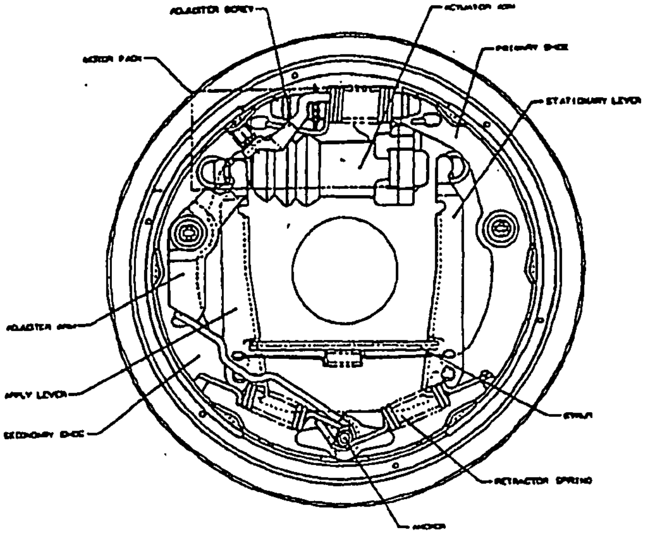


Figure 4 - Rear Electric Brake

Two key requirements drive the basic design concept. The first requirement is precise proportional control facilitated by use of a highly efficient motor, gear train, and lever system. Sliding mechanisms and associated friction losses are minimized by design. Bearings position and support all rotating shafts. A ball screw provides high efficiency and robustness to contamination. The levers utilize pivoting, rather than sliding, contact at the high load connection points. This reduces sensitivity to contamination from debris and corrosion.

The second key requirement is driven by default mode concerns. The wheel brake must mechanically reduce braking to an acceptable level upon power removal; the wheel brake must not remain energized in cases of power interruption during braking. This requires a highly efficient system with a return spring mechanism to "backdrive" the brake without the assistance of electrical power. The "backdrive" capability necessitates a separate park brake latch mechanism.

The rear electric brake system park brake latch mechanism is a bi-stable, spring loaded, clutch device which locks the main motor shaft upon command. The wheel brake mechanically latches at a maximum holding capability until the park brake switch deactivates. The system requires ignition "on" to deactivate the park brake.

NO electrical power is necessary to retain park brake engagement.

MEETING INCREASING REQUIREMENTS

The application of intelligent brake control meets the increasing requirements of future vehicles including (1) minimized variability through closed-loop control; (2) active proportional brake control for ABS, traction control, handling management, and brake activated collision avoidance; (3) tunable ergonomics to provide optimum driver control and comfort and; (4) appropriate interfaces with other vehicle operating systems including powertrain and energy recover systems.

CLOSED LOOP CONTROL

Closed loop system control greatly reduces th effects of component and operating condition variabilit Differential wheel speed information feeds the algorithm fc compensation from changes in wheel brake output and vehicl load distribution. Front-to-rear balance due to load variatio is maintained at 90 plus percent braking efficiency above 0. g deceleration. Test results with and without such dynami control are depicted in Figure 5.

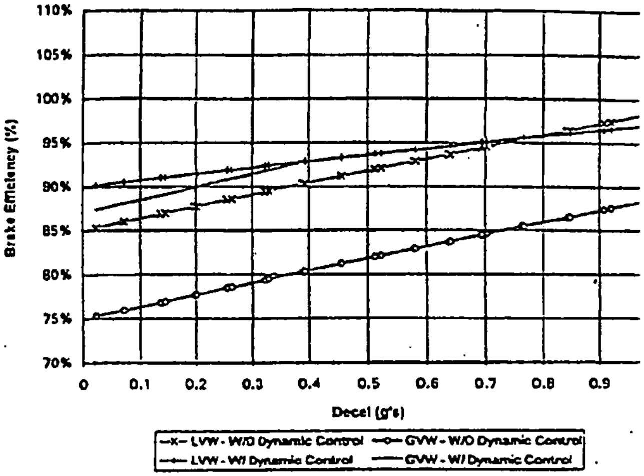
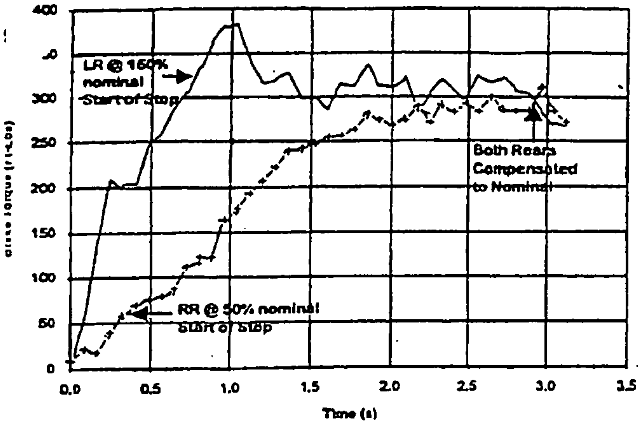


Figure 5 - Brake Efficiency

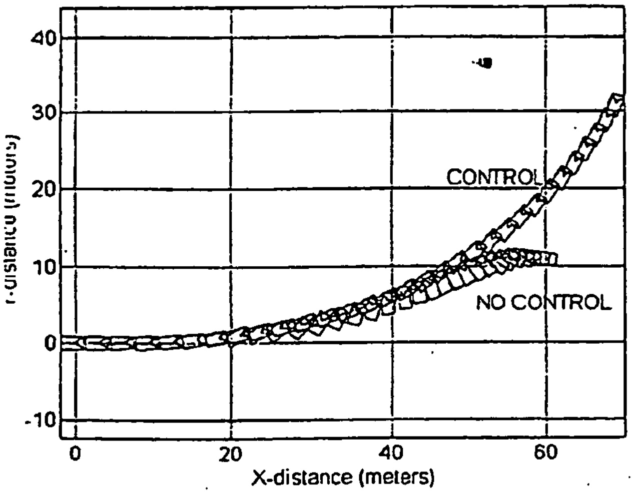
This same basic control algorithm also compensate and thus reduces side-to-side variability. These variatior become transparent as algorithm control alters comman torque. Figure 6 depicts two wheel brakes with intentionall differing open loop output being compensated for brakin torque by closed loop control. Notice in this example the le rear brake torque reduces while the right brake torq increases to match the total desired axle torque and provic commanded deceleration. The intelligent algorith memorizes these wheel brake characteristics to compensa during initial activation of subsequent stops.



'igure 6 - Side-to-Side Compensation

CTIVE CONTROL

The system has the capability to assume full four-/heel independent control for ABS, traction control, adaptive ruise, handling management, and automated highway ınctions. For example, brake augmented handling ıanagement optimizes vehicle response by independently ating any or all of the wheel brakes. The resultant brake ated yaw forces improve vehicle maneuverability and andling predictability. Figure 7 depicts differing vehicle yaw ontrol with and without brake system intervention.



igure 7 - Yaw Control

TROLLABLE ERGONOMICS

Tunable pedal feel provides optimum driver rgonomics. The algorithm has full control of apply system ains. Thus, pedal travel, force, and damping characteristics re easily calibrated. This ensures optimum performance independent of wheel brake parameters. If desired, ergonomics can be mechanized to allow driver adjustment within acceptable limits.

APPROPRIATE INTERFACES

Integration of brake controls with other vehicle systems opens numerous possibilities of greater vehicle performance. An example is the greater electric vehicle operating range obtained by integrating brake with powertrain controls. Full utilization of regenerative braking increases electric vehicle operating range by 25%. However, available regenerative braking varies upon several operating conditions such as state of battery charge and vehicle speed. Integration of brake and propulsion controls allows maximum energy recovery with minimal friction braking. This dynamic interaction between the vehicle's brake and propulsion systems is transparent to the driver. Figure 8 shows an example of a uniformly decelerating vehicle with varying retardation from the propulsion and wheel brakes.

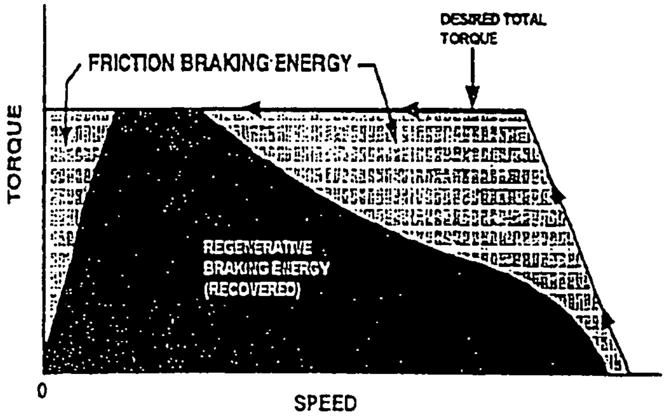


Figure 8 - Blended Regenerative and Friction Braking

SUMMARY

Intelligent brake control systems will provide the high levels of performance, value, low mass, low parasitic losses, and design flexibility required by future vehicles. Some of these features are now on the road in applications such as the GM Impact Preview Fleet, and are daily demonstrating their capability.

As new vehicles are designed, we strongly believe the advantages of these brake systems will set the standard for next levels of vehicle performance.